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Experimental tests on seismically damaged composite steel concrete walls retrofitted with CFRP composites

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ABSTRACT

This paper presents the results of an experimental program on two composite shear walls with steel encased profiles (CSRCW), damaged under cyclic lateral loads and thereafter retrofitted and retested. The experimental program was conceived in order to analyze the possibilities of using CFRP materials for strengthening the CSRCW affected by seismic action. The Carbon Fiber Reinforced Polymer (CFRP) composites are becoming more frequently used in strengthening structural elements due to their superior characteristics and simple technology. From the damaged elements obtained in the first phase of the research program, two shear walls with steel encased profiles were selected to be retrofitted and retested. According to a thorough literature survey, the number of experimental campaigns on reinforced concrete walls (RC) retrofitted by FRP composite is rather low, compared to the large number of other structural members, and it does not exist for CSRCW. This paper presents an effective strengthening solution that can be applied to damaged elements to evaluate the availability of partial confinement, applied to parts with locally deteriorated strength. The retrofitting solution uses CFRP strips and plates, to restore the wall bending resistance and to provide a confinement effect at the ends. The experimental results indicate that the performance of the elements CSRCW_R, repaired and retrofitted, was similar to the reference elements in terms of load bearing capacity, but slightly smaller in terms of stiffness and energy dissipation capacities.

1. Introduction

The use of the composite steel concrete shear walls with steel encased profiles CSRCW can be one of the alternative solutions for a lateral load resisting system. This system can provide during earthquakes lateral stiffness, high shear and flexural capacity, ductility and energy dissipation.

Due to the large number of earthquakes produced in the last decade, the researchers have studied possible solutions for retrofitting structural elements affected by the seismic action. Since in many cases, the solutions must be conceived to assure the same distribution of the seismic loads, no major stiffness changes are allowed in the existing structures. Otherwise, the deformation capacity and the load bearing capacity of the element have to be reevaluated after the repairing and strengthening of the damaged element. If the initial ductility factor "*q*" is maintained in the retrofitted structure design process, the designers have to assure the required local ductility, for the repaired and strengthened structural members. Unless this condition is assured, the failure mechanism of the structure can be unexpected and the local brittle fracture of such members can produce the collapse of the entire building.

The reinforcement effectiveness of the fiber-reinforced polymer (FRP-EBR) externally bonded is widely used, either to increase the shear strength of the reinforced concrete members or to provide the critical region confinement of the members. Recent research on reinforced concrete walls strengthened with FRP composites were conducted by Li and Lim [1], Antoniades et al. [2,3], Demeter et al. [4], Kitano et al. [5], Lombard et al. [6], Hiotakis et al. [7], Ghobarah and Khalil [8]. Other research presented by Li and Pan [9], Wei et al. [10], Hatami el al. [11], showed the ability to restore the initial performances of the structural members repaired and strengthened with FRP composites.

A theoretical and experimental research program on the behavior of the composite steel concrete walls with steel encased profiles was conducted in the Civil Engineering Department at the Politehnica University of Timisoara, Romania. Five possible solutions of composite walls (called CSRCW1–5) and one for a reinforced concrete typical shear wall (CSRCW6) were designed and laboratory tested [12,13]. The tests were performed under constant axial compression and cyclic lateral loads. Out of these five composite specimens, two were tested prior to failure (CSRCW2 and CSRCW4), retrofitted with CFRP composites and retested. Since the solution of using steel profiles at the boundary of shear walls is relatively new, there is no experimental research literature on the retrofitting solution for this type of post-damaged elements.

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Nomenclature

α_1	multiplier of horizontal design seismic action at formation of first plastic hinge in the system
α_u	multiplier of horizontal seismic design action at formation of global plastic mechanism
Δ_y	conventional elastic limit
Δ_u	total drift for 85% of P_{max}
ε	strain
E_s	steel modulus of elasticity
f_y	yield strength of steel
f_u	ultimate strength of steel
ϕ	diameter of rebars
K_{first}	initial stiffness
K_j	stiffness at j displacement level
μ	displacement ductility
N	constant axial load (vertical) applied to CSRCW_R
ν_d	normalized axial force
P	horizontal load
P_{max}	ultimate horizontal load capacity
$P_{85\%}$	85% of ultimate lateral load capacity (P_{max})
t	CSRCW thickness
q_{sr}	over-strength factor

The paper aims to comprehend the seismic performances of CSRCW retrofitted with FRP composites. The most important issues related to the seismic performance, i.e. lateral stiffness, horizontal displacement (drift), ductility and energy dissipation capacity are presented and discussed for CSRCW_R elements in comparison with the CSRCW reference elements. The behavior of the tested elements also include: the crack patterns, the failure modes with the final edges conditions, the relation between lateral load and the displacement at the top of the walls, the strain analysis in structural steel, reinforcements and FRP composites. Some remarks are also presented for the anchorage system used.

2. Experimental program

The experimental program consists of six 1:3 scale elements (CSRCW1–6), presented in detail in Dan et al. [12,13]. Two specimens (CSRCW2 and CSRCW4) were selected for retrofitting with CFRP composites. These elements were tested both prior to failure and after retrofitting, to investigate the strengthening effect and the seismic behavior efficiency. The retrofitted elements CSRCW2_R and CSRCW4_R are referred to with an "R" suffix to the original specimen names.

The experimental specimens had: 3000 mm height, 1000 mm width and 100 mm thickness. The wall panels were fixed in reinforced concrete foundations of 1500 mm length, 400 mm height and 350 mm width. The structural steel profiles connected in the concrete web with headed shear stud connectors with d = 13 mm diameter and h = 75 mm at 150 mm interval. The reinforcements of the reinforced concrete (RC) web panel are made with: Ø10 mm vertical bars (1.57% steel ratio), Ø8/150 mm horizontal bars (0.67% steel ratio) and horizontal stirrups (0.67% steel ratio). The configuration of the two specimens selected for retrofitting is presented in Fig. 1.

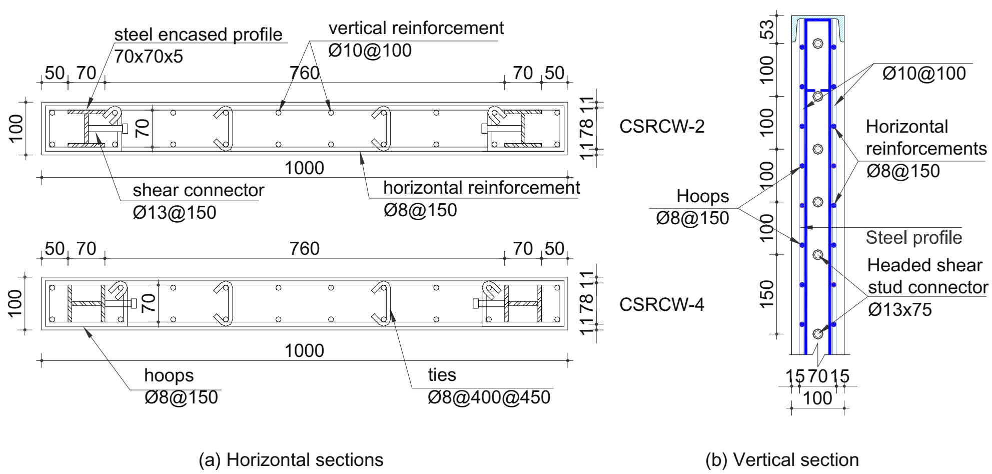

Fig. 1. Reference elements configuration (mm).

Table 1
Material properties of steel.

Type		Rebar diameter/plate thickness (mm)	f_y (N/mm^2)	f_u (N/mm^2)	E_s (N/mm^2)
Steel rebar	d8-1	8	483	616	2.09×10^5
	d8-2	8	484	616	2.05×10^5
	d8-3	8	471	617	2.01×10^5
	d10-1	10	526	626	2.10×10^5
	d10-2	10	559	624	2.15×10^5
	d10-3	10	558	616	2.09×10^5
I-Shaped steel	s-01	7	328	515	2.00×10^5
	s-02	7	324	513	2.01×10^5
	s-03	7	331	521	2.05×10^5